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On Wire Ropes.

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That wire rope as a mechanical means of cheaply conveying coal is being superceded by electricity and compressed air is not admitted by many mining engineers.

After many years of careful study of the three systems and closely watching the actual application of them all, we are fully convinced that wire rope haulage will live on after some of the new fangled systems have settled down to their proper sphere. That compressed air and electricity have many advantages in some respects, it is not our purpose to controvert, but that wire rope haulage actuated by steam, electricity or compressed air has a wider field than either the compressed air or electrical locomotive is our contention. If this be admitted as correct and, whether or no, it certainly is the duty of all mining engineers and colliery managers to have as complete a knowledge about wire ropes as is possible in one having so many diversified duties to perform, so that he will not be entirely at the mercy of the rope manufacturer who has his little "trick of trades" in common with most other manufacturers.

It is the writer's intention in this short paper to give some practical and theoretical notes on wire ropes, not claiming any originality, in the hope that they may be beneficial to the younger members of the profession.

Wire ropes for mine use are generally composed of:—

(1). Six wire strands composed of seven wires each, twisted on a hemp centre. The centre wire of the strand sometimes being soft.

(2). Six wire strands composed of twelve wires each, twisted on a hemp centre.

(3). Six wire strands, composed of nineteen wires each, twisted on a hemp centre.

This construction is sometimes varied so that there are 13 larger wires and 6 smaller wires in each strand, but the general construction of the rope is the same.

The ratios of the diameter of the individual wires to the diameter of the rope in these three cases, not including the rope with two sized wires as in No. 3, are as follows: (1) $\frac{1}{9}$, (2) $\frac{1}{12}$, (3) $\frac{1}{15}$. From this, the gauge of wire required to constitute a rope can readily be got to a close approximation.

No. 1 is only used where large wheel drums and easy curves can be employed. Such a condition does not very often present itself in coal mines. The No. 2 rope is a more pliable one and can be used on smaller drums, wheels, and curves, but when we remember that the size of the individual wires govern the size of wheel it will be seen that with this rope, with a heavy load, such as is usual in mine haulage, the wheels would be relatively large. A wire should not be bent over a wheel less than 1,000 times its diameter for good results in length of life and tons hauled.

Excepting in ropes of large diameter No. 3 is not used for mine haulage but is largely employed for hoisting ropes.

To meet the conditions of severe bending usual in the underground working of collieries the British manufacturers construct a compound rope which we will designate as (4):

(4). Six wire strands, each composed of 9 large wires twisted around 7 smaller wires (the centre or seventh wire being soft), twisted round a hemp centre. The gauges of wire used and number of wires used in the construction of a compound rope are varied to suit the circumstances. These ropes are very servicable and meet the mine manager's wants with a wonderful degree of satisfaction.

I am not aware that any American rope makers are constructing ropes of this style.

In computing the strength of any twisted wire rope it is well to remember that the strength of each individual wire is reduced from 4 per cent. to 10 per cent. by twisting. The makers claim the strength is reduced 4 per cent. while disinterested experimenters claim the strength is reduced 10 per cent. Perhaps a fair allowable reduction of strength for twisting in manufacturing, would be the average of the two, viz: 7 per cent.

Iron wire ropes are not suitable for mining purposes and are not considered in this paper.

There is a very wide range in the grades of steel ropes and as the breaking strength per square inch of section of the material of which they are constructed is fundamental, we herewith give a short table which will make the point clear.

NAME.	Homogeneous Steel.	Patent Improved or Crucible Steel.						Plough Steel.			
Quality	Tons. 40-45	Tons 60	Tons. 75	Tons 80	Tons. 85	Tons 90	Tons. 95	Tons 100	Tons 105	Tons. 110	Tons. 120

The quality here is in tons of 2,240 lbs. per square inch of section.

The composition that enters into these grades is partly a secret of the manufacturer, however, a vast amount of information has been published but the articles are too numerous and conflicting to be brought within the limits of this paper.

For the purpose of making the above tables clear let us take an example: Suppose we are going to use a crucible steel rope 15-16 inch diameter, or 3 inches circumference, composed of six strands, each strand having 9 wires .080 inch diameter, twisted over 7 wires .054 inch diameter, of 201,600 lbs. breaking strain per square inch, what is the breaking strain of the rope?—

.08² in. x .7,854 x 201,600 lbs. = 1008″ x 9 wires.		9,072 lbs.
.054² in. x .7,854 x 201,600 lbs. = 461.7″ x 6* wires.		2,770 lbs.
Strength of one strand		11,842 lbs.
		6
11,842 lbs. x 6 strands......		71,052 lbs.
Less 7 per cent. allowed for twisting..		7,105 lbs.
Breaking strain of rope		63,947 lbs.
† The safe working load in underground haulage may be from 1-7 to 1-5 say 1-6..................		10,658 lbs.

* Six of the seven small wires only enter into this calculation as the seventh wire is the core of the strand and is soft having little tensile strength.

† A rope running at a low speed and no lives depending upon it, is not subject to the sudden strains of a high speed rope and may have a very low factor of safety. In slow endless rope haulage 1-2 miles per hour, we think, 5 is a safe factor. But with fast running tail-ropes 7 is not too large. For hoisting ropes the safe factor should be 10.

The following we regard is a good sample of a specification for wire rope :—

Quality of Wire.—1. All steel used in the manufacture of the cable shall be of the "best selected patent improved crucible steel" drawn to a uniform diameter throughout, and capable of withstanding the tests mentioned in the table given below.

Length, size and form of Wire.—2. The cable shall be feet long and shall have a circumference of 3⅝ inches (three and five-eighths) when finished. It shall consist of six outside strands laid up in the formation known as the "Lang lay," with the lay in the rope in the same direction as the lay in the strands.

Strands.—3. Each strand shall be composed of seven wires .115 inch in diameter, laid round a core consisting of five wires .061 inch in diameter round one wire .049 inch diameter.

Spinning.—4. Each strand shall be spun in feet lengths and evenly wound direct from the machine on to a reel. When it is necessary to join either the outside or inside wires they shall be properly scarfed and brazed.

Closing.—5. The six strands shall be closed under uniform tension round a heart consisting of the best white manilla rope, having three strands, hard laid, and well soaked in oil.

Lay.—6. The lay of the wires in the strands shall be 3¾ inches (three and three-quarters) and the lay of the strands in the cable 9½ inches (nine and one half).

TABLES OF TESTS—7.

TENSILE TEST.

Diameter of wire.	Length of test, piece between gauge marks.	Tensile test. Stress per square inch.	Stress per wire.
.115 inch.	8 inches.	90 tons	2,094 lbs.
.061 "	8 "	85 "	556 "
.049 "	8 "	85 "	359 "

Here the core wire of the strand is not soft as in the case we made the calculation for.

DUCTILE TEST.

Length of test, piece between gauge marks.	Number of twists.	Bends to 180° over one-quarter inch radius.
8 inches.	25 number.	3 number.
8 "	45 "	6 "
8 "	58 "	10 "

Each Hank to be subjected to test.—8. Before proceeding with the manufacture of the cable, the contractor shall submit every hank of wire to the engineer, who will make tensile and ductile tests from each end of the hank before it is worked into the cable.

Variation from specified tests.—9. Every hank which shall be found to vary more than 2½ per cent. in either direction from the tensile tests specified above, or more than 8 per cent. below the specified number of twists in 8 inches will be rejected.

Test of Cable.—10. The contractor shall make the cable sufficiently long to allow for cutting off a suitable portion which shall be tested for tensile strength in the presence of the engineer, or his representative, and must withstand a load of 43 tons (ton here is 2,240 lbs.) without breaking.

Cost of making tests.—11. The cost of all tests, whether made at the contractor's works or elsewhere, shall be borne by the contractor.

Chemical tests.—12 In addition to the above, chemical tests may be made at the discretion of the engineer.

	Outer wire. .115 in. diam.	Inner wire. .061 in. diam.	Core wire. .049 in. diam.
Carbon	.50 %	.50 %	.50 %
Silicon	.06 "	.06 "	.06 "
Manganese	.50 "	.50 "	.50 "
Phosphorus	.045 "	.045 "	.045 "
Sulphur	.040 "	.040 "	.040 "

"Manganese imparts toughness and neutralises "shortness," it further acts in favor of the presence and functions of the carbon." Silicon can only be tolerated in very limited quantities, whilst phosphorus and sulphur are the greatest enemies encountered in the manufacture of steel. Any excess of silicon produces brittleness, which is more marked as the percentage of carbon is raised. Small quantities of sulphur present in steel will produce unsoundness and "red shortness" whilst phosphorus is detrimental on account of causing "cold shortness" besides being an enemy to any form of tempering and conductivity."—*Smith.*

In the ordinary construction of wire ropes the wires forming the strands are twisted to the left hand but the strands are twisted to the right hand, or opposite direction. In the "Lang lay" the wires forming the strands and the strands comprising the rope are all laid in the same direction. Ropes may be laid up "right" or "left" hand and this is no small consideration in the life of a rope if one coil chafes on another. If, when standing behind the drum facing the pit head pulleys, the rope travels on drum from left to right, the rope should be laid "right handed," or vice versa. The tendency to mount and side friction are minimised.

The "lays" adopted in wire rope making are principally dependent upon the gauge of the wires employed, the size of the rope to be made, and the purposes they are intended for. Approximately it may be said that the "lays" in strand, vary about three to four times the diameter of the rope and the "lays" in the rope vary from seven to ten times the diameter of the rope.

The average elongation of ordinary constructed rope is about 3 per cent. and with "Lang lay" 1½ per cent. to 2 per cent. which

must not be lost sight of in hoisting ropes and endless ropes. A suitable tightening arrangement will take up the elongation in endless ropes but in hoisting ropes it is a case of pulling the rope up in the fastenings in the drum.

With hoisting ropes the life can be greatly increased by ordering sufficient length to enable 6-10 feet to be cut off the end periodically and thus change the point of lift or stress.

It is of the first importance that ropes be greased frequently and carefully with a good, pure, grease which is absolutely free from acids. A grease with acids in it is worse than no grease.

It is obvious where ropes have to bend round wheels, drums, or curves, that the outer fibres of *each wire*, as they accommodate themselves to the curvature, are in tension, and the inner wires in compression, while the center or neutral axis is unchanged. As a consequence it may be assumed that the more flexible a rope, *i. e.* offers less resistance in compression and tension in each wire, where it is subjected to much bending in work, the better will be the results, provided that such flexibility be not obtained by the use of such fine wires that the wearing capacity of the rope is affected.

We said in the early part of this paper that a rope should not bend over a wheel less than 1,000 times the diameter of the largest individual wire in the rope. This is built up on assuming $S = 30{,}000$ from which we have $D = \frac{30{,}000{,}000\,d}{30{,}000} = 1{,}000\,d$. This only implies, after all, that if D is greater than 1,000 d the life of the rope will be greater and *vice versa*.

A prominent rope-maker in England answers a letter of enquiry from us asking his rule by which to calculate the size of wheel for a given size of rope as follows :—

"In haulage it is advisable to use the largest pulleys you can possibly get in; this however is governed a great deal by the conditions under which you have to work, and when we know the size of the pulleys you are using we can generally suggest to you the class of rope most suitable. There is no rule for this, but it is purely a matter of experience and how ropes have worked under similar conditions in other places."

However we know we have two stresses "tensile" and "bending" which we can fairly well approximate by which we "get out of the woods."

The "tensile strain" we will take to mean the dead load and the "bending stress" to mean the extra load due to bending which must be added to the "tensile stress" for the total load.

The generally accepted formula for bending stress is $S = E\frac{d}{D}$ in which

$E =$ Modulus of elasticity which is variable. For steel we will call it 30,000,000. pounds per square inch.

$d =$ Diameter of a single wire of the rope in inches.

$D =$ Diameter of pulley in inches.

$S =$ Stress per square inch of section exerted upon the outermost wire of the rope in pounds.

Reverting to example given above; the diameter of the outer wire is .08 inch and, using a pulley 1,000 times diameter of wire (here use only for convenience) we have $d = .08$ inch and $D = 80$ inches.

$$S = \frac{d}{D} = 30{,}000{,}000 \ \frac{.08 \text{ inch}}{80 \text{ inches}} = 30{,}000 \text{ lbs.}$$

The cross sectional area of the two sizes of wire in that example is :—

		Sq. in. area.		wires.		Sq. in. area.
$.08^2$ inch $\times$ .7854	=	.005026560	$\times$	54	=	.27143424
$.054^2$ inch $\times$ .7854	=	.002290223	$\times$	36	=	.08244803
						.35388227

.35388227 x 30,000 lbs. = 10616.5 lbs. stress due to bending.

The stress produced on the tension side by bending, must be considered in connection with the stress produced by the load in order to arrive at the total stress. In order to avoid a permanent set, it is necessary that the sum of these two stresses should not exceed the elastic limit.

In our example by using a safe factor of 6 we allowed a load 10,658 lbs. but when we add the bending stress we get 10,658 + 10616.5 = 21274.5 lbs. The breaking strain was 63,947 lbs.;

$$\frac{63{,}947 \text{ lbs.}}{21274.5} \quad 3+ \text{ safe factor.}$$

In the example the factor 6 was allowed to overcome bending stress, sudden jerks, etc. By finding the bending stress we see that factor a of 3 is ample to pnt up for the other possible stresses. A threefold security is considered sufficient.

Whatever may be the relation of these two stresses, pulling and bending, the total stress on the rope will be that due to the combination of these two stresses.

If $\frac{D}{d}$ is made so small that the two stresses, pull and bending, are greater than the elastic limit the rope will receive a permanent set which, however, is not always dangerous.

In this connection we might call attention to the baneful effect attending the use of wire ropes where reverse bends are made. Careful record and experiment have shown that the life of the winding rope which goes over the pit-head pulley and under the drum is only from one-half to three-quarters as great as the rope which goes over the pit-head pulley on to the top of the drum.

The importance of greasing ropes is also accentuated by Mr. Biggart's tests. Two lengths of the same size and manufacture of rope were used; the unoiled length made only 16,000 whereas the oiled length made 38,700 bends over the same pulley before breaking. Other similar pieces of rope unoiled would run over a 24 inch pulley 74,000 times, and the oiled length 386,000 times.

This paper has assumed proportions we had not intended when undertaking its compilation, and indeed it has been compiled on lines that we had not intended when commencing it. Such a paper as this cannot be considered complete without considering many other important points in wire rope construction, and its use, such as the neutral axis, the proper diameter of sheaves, curves, etc. At some future time we may send in another paper covering these important points.